Doctoral Thesis Committee Meeting

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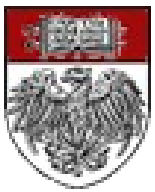
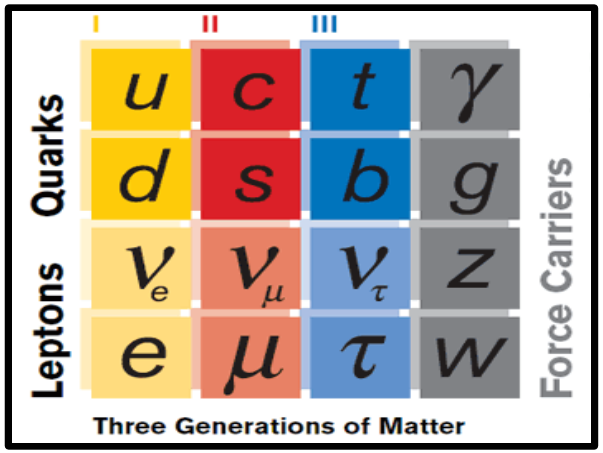


Introduction

- Introductions
- The Problem
  - Standard Model of Particle Physics
  - Searches Outside the SM: displaced verticies
- Phenomenology
  - Hidden Valley Model
- Signal Monte Carlo Studies
  - Look for basic discriminants
- The Analysis

The Standard Model



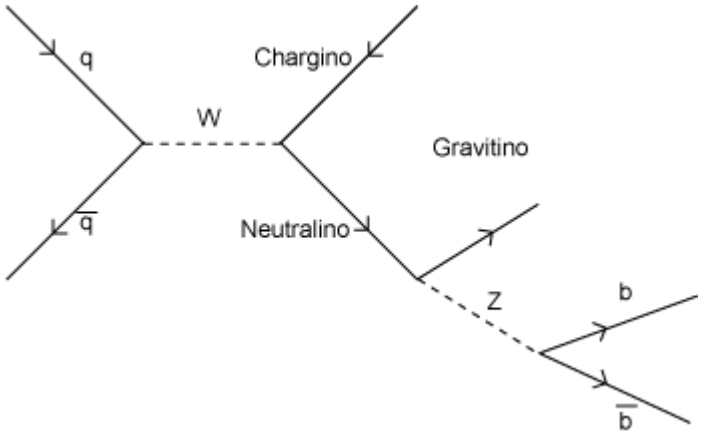
- The Standard Model (SM)
  - One of the best measured theories in physics.
  - So we're done, right?
  - It turns out the standard model is incomplete.
  - Plus there is that elusive Higgs boson that keeps slipping through our fingers.
- New physics searches
  - Why? A: Not to get too philosophical, but why not?
  - One of the many definitions of science is probing the unknown.
  - At FermiLab we have the world's largest (soon to be second-largest) "flashlight" with the ability to look into the unknown.
- Where/How do we look?
  - Look at a specific signature that is interesting and may be a window into new physics, e.g. displaced verticies.

Displaced Verticies

- Why look at displaced verticies?
  - It is an interesting signature outside of the SM.
  - While there are long lived particles in the SM (K, D, & B hadrons) there are few SM processes for two objects originating from a single common vertex.
- Some Previous Analyses:
  - Done at CDF-looking for a long-lived particle decaying into $Z^0 \rightarrow \mu^+\mu^-$ by looking at the tracking information.
    - Finds the track intersection of the muons, and looks for a large distance between this intersection and the primary vertex.
  - Done at D0-looking for a long-lived particle decaying into $Z^0 \rightarrow e^+e^-$ by looking at calorimeter information.
    - D0 Electro-Magnetic calorimeter is finely segmented, allowing for vertex resolution.
- Because we can.
  - CDF employs a Silicon Vertex Trigger (SVT) that can trigger on displaced tracks.
  - This trigger allows us to enrich our signal while reducing the QCD background present at hadron colliders.
- What are we looking for:
  - In general we are searching for a long lived object decaying into two quarks, which then hadronize into jets in the detector.

Phenomenology

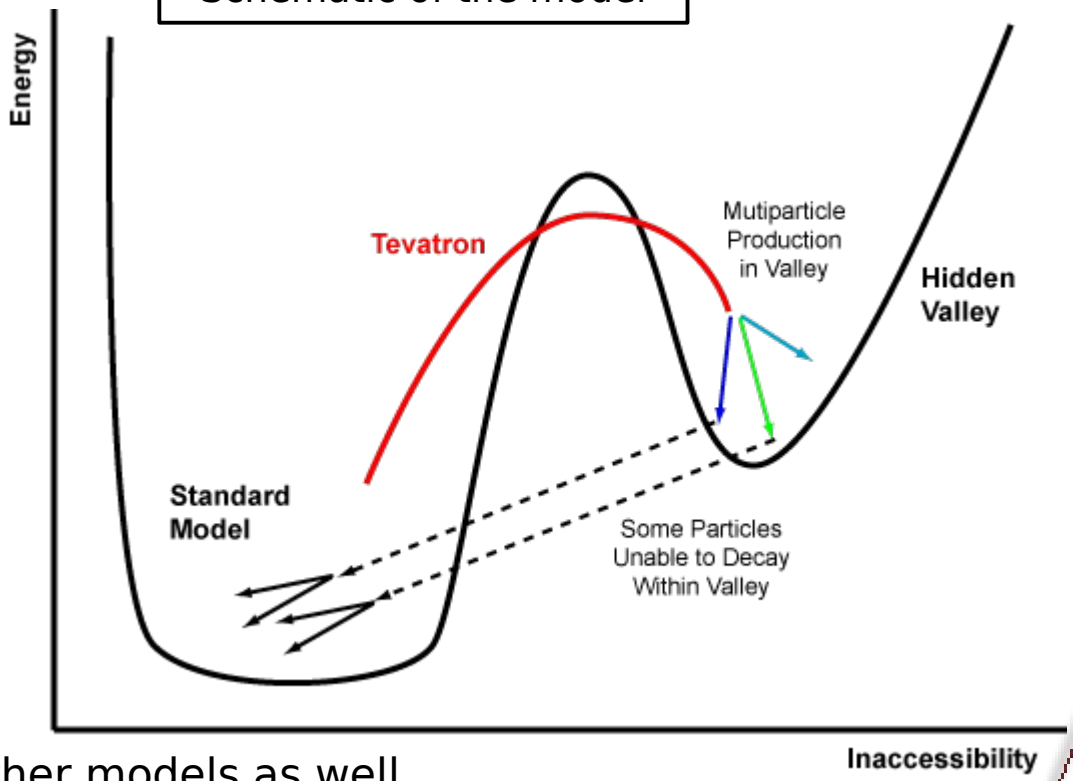
- There are a number of theories where displaced verticies play a role.
  - Hidden Valley model by Matt Strassler (Rutgers) and others.
    - The SM communicates with a Hidden Valley with valley (or v-) particles.
    - We wound up adopting this model for our search.
    - See next slide for more details.
  - Gauge-mediated SUSY models where the gravatino is the Lightest Stable Particle (LSP).
    - If the next to lighted stable particle (NLSP) has a large $\widetilde{Z}$ content, then it may decay to a Z^0 boson and the LSP.
    - The sparticle content of the NSLP is a free parameter in some SUSY models.



Hidden Valley

- Energy from collisions enter into the new sector.
- It is transformed into multiple particles through the dynamics of the new sector.
  - These valley-particles (or v-particles) behave in the same way as SM particles.
  - They obey a "v-QCD,"
  - Most likely decay is a v-π.
- Some of these particles decay back into SM particles.

Schematic of the model



- This model can co-exist with other models as well.
  - SUSY, technicolor, etc.
- It may help in the search for the Higgs.
  - The Higgs may decays into long-lived neutral v-particles, which are heavy and meta-stable. They would decay at a displaced vertex.
  - These would then decay into the heaviest SM fermion available (b-quarks).
- Because this sector is dark, there may be Dark Matter/Astrophysics connections as well.
- In some models (see Kaplan, Luty, Zurek) $c\tau$ for the heavy metastable particle could be of order 1 cm.

Hidden Valley

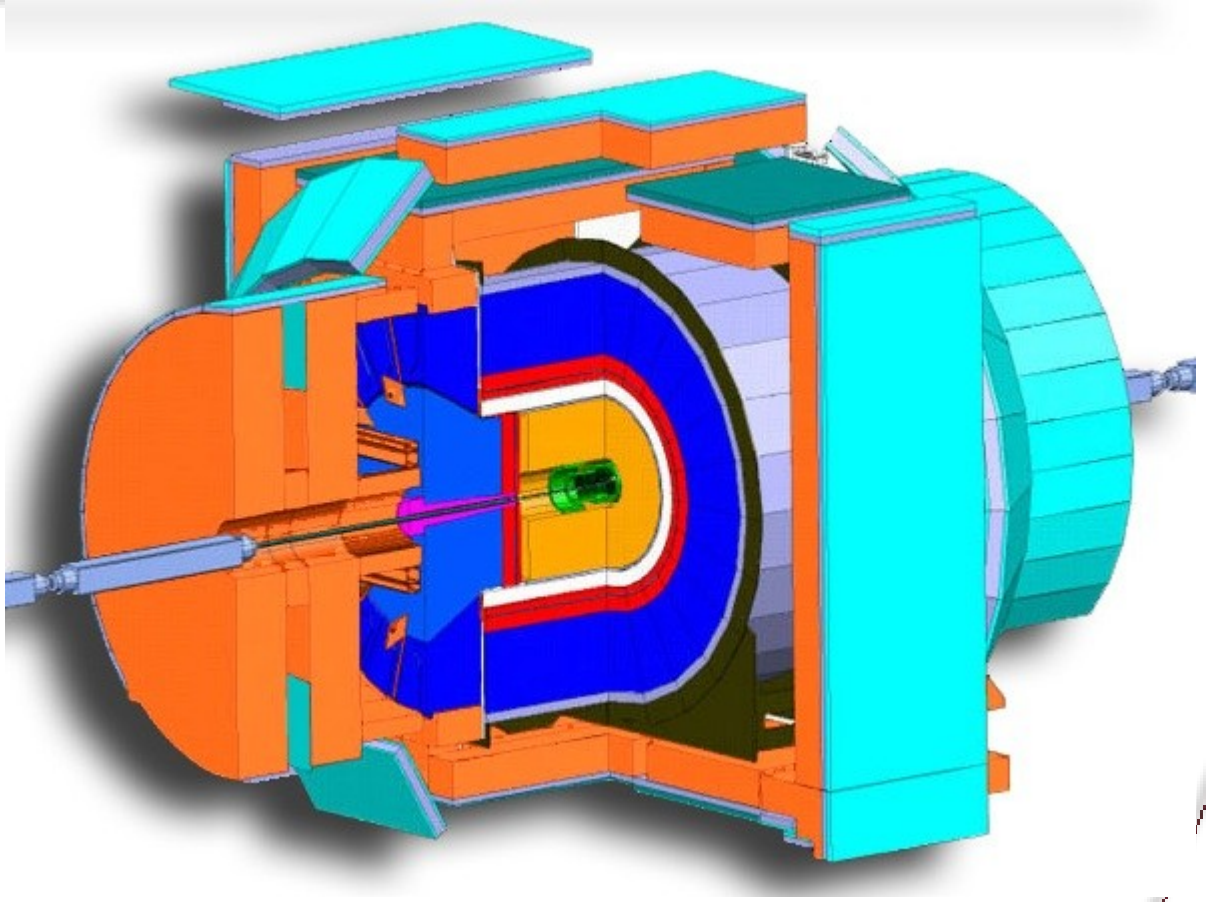
- The Hidden Valley model provides a large, and dark, sector which is weekly constrained by current experiments.
  - In general, experiments at LEP, CDF, BABAR have little or no constraints on neutral particles with small couplings to photons or Z^0.
  - In particular particles that have no weak, electric or color charge.
- Because this model has few constraints, there are a large number of experimental signatures that are possible.
  - We have chosen to concentrate on one signature, displaced verticies, and one model, Higgs production.
  - The signature provides sensitivity to a broad range of heavy metastable particles.
  - The model provides a benchmark result that can later be translated for other theories.

FermiLab

- FermiLab is the home of the Tevatron, a proton-antiproton accelerator and collider.
- Proton-antiproton collisions occur at a center of mass energy of 1.8 TeV.
- CDF is one of two detectors (D0) located along the main ring (rear ring in photo).

Collider Detector at Fermilab (CDF)

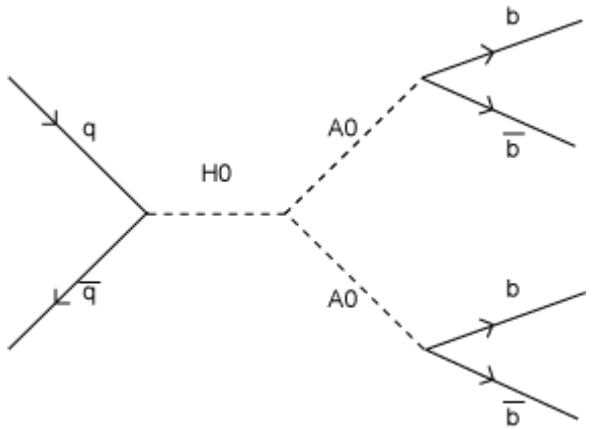
- CDF is a cylindrically symmetric multi-purpose particle detector.
- Major components consist, from inside to out:
  - Silicon strip tracker (SVXII) (green)
  - Wire tracking chamber (COT) (orange)
  - 1.4 T Solenoid (white)
  - Electromagnetic and Hadronic calorimeters (red) and (blue)
  - Series of wire chambers and scintillators, collectively the “muon system.” (cyan)



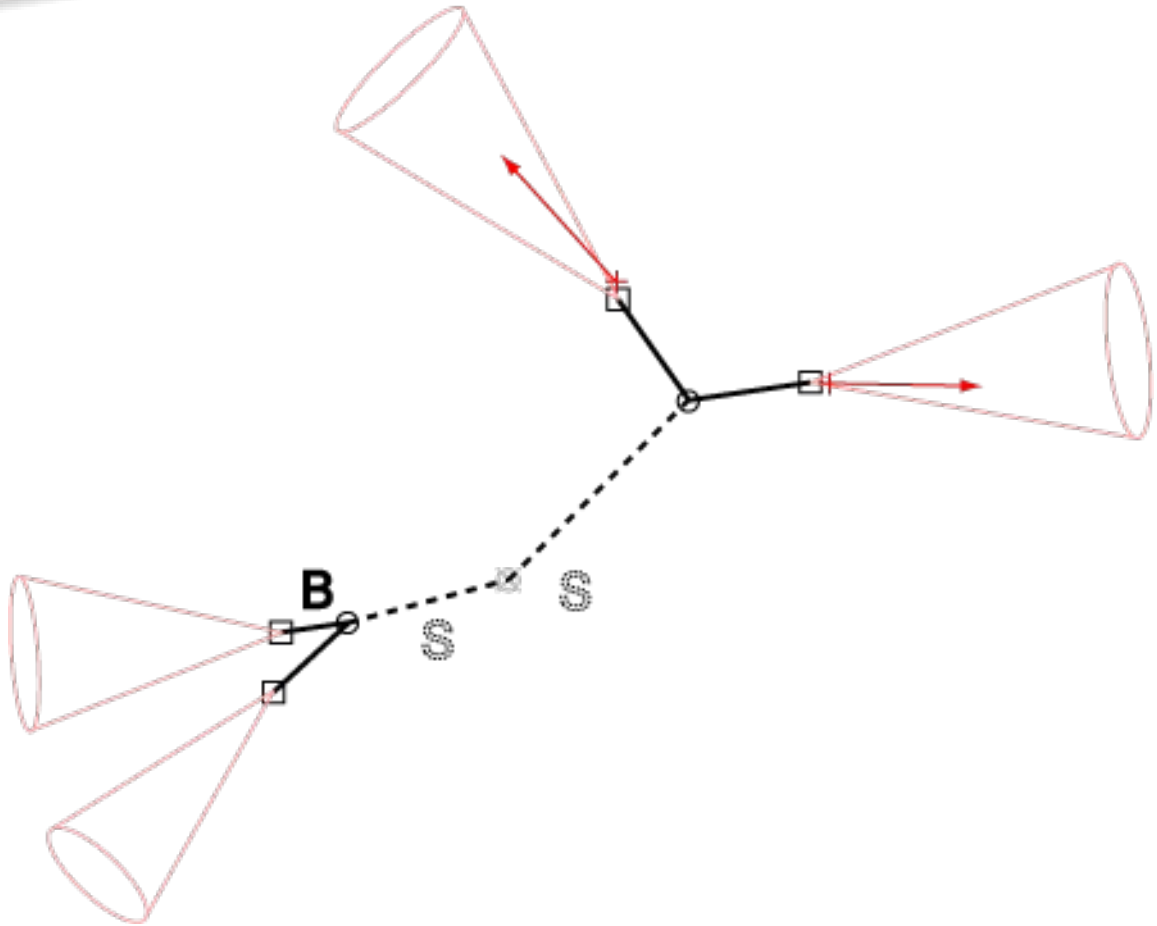
- For this analysis we use nearly all these systems, especially the silicon tracking system.
  - There is a silicon track trigger (SVT) which can trigger on displaced tracks.

MC Studies

- First thing we did was generate some signal MC to study. This was done with Pythia w/ the CDF detector simulation and CDF "tunes."
  - The decay chain is: $H_0 \rightarrow A_0$ $A_0 \rightarrow$ b,bbar, b,bbar.
  - Here the Higgs is a MSSM Higgs.
    - The Higgs has been constrained to decay into A_0s.
  - The A_0 represents a hidden valley particle (v-π) that has a long lifetime.
    - The proper lifetime studied so far is $c\tau$ = 1.0 cm.
  - We generate different masses of H_0s and A_0s.
    - H_0 = 130 GeV and 170 GeV
    - A_0 = 20 GeV, 40 GeV, and 65 GeV
  - The A_0s are constrained to decay into b, bbar quark pairs.
  - The MC also simulates an underlying event.



Model Diagrams



Here the Higgs decays at the primary vertex (the X). S represents the heavy pseudoscalar with a long lifetime, which decays into bbbar pairs.

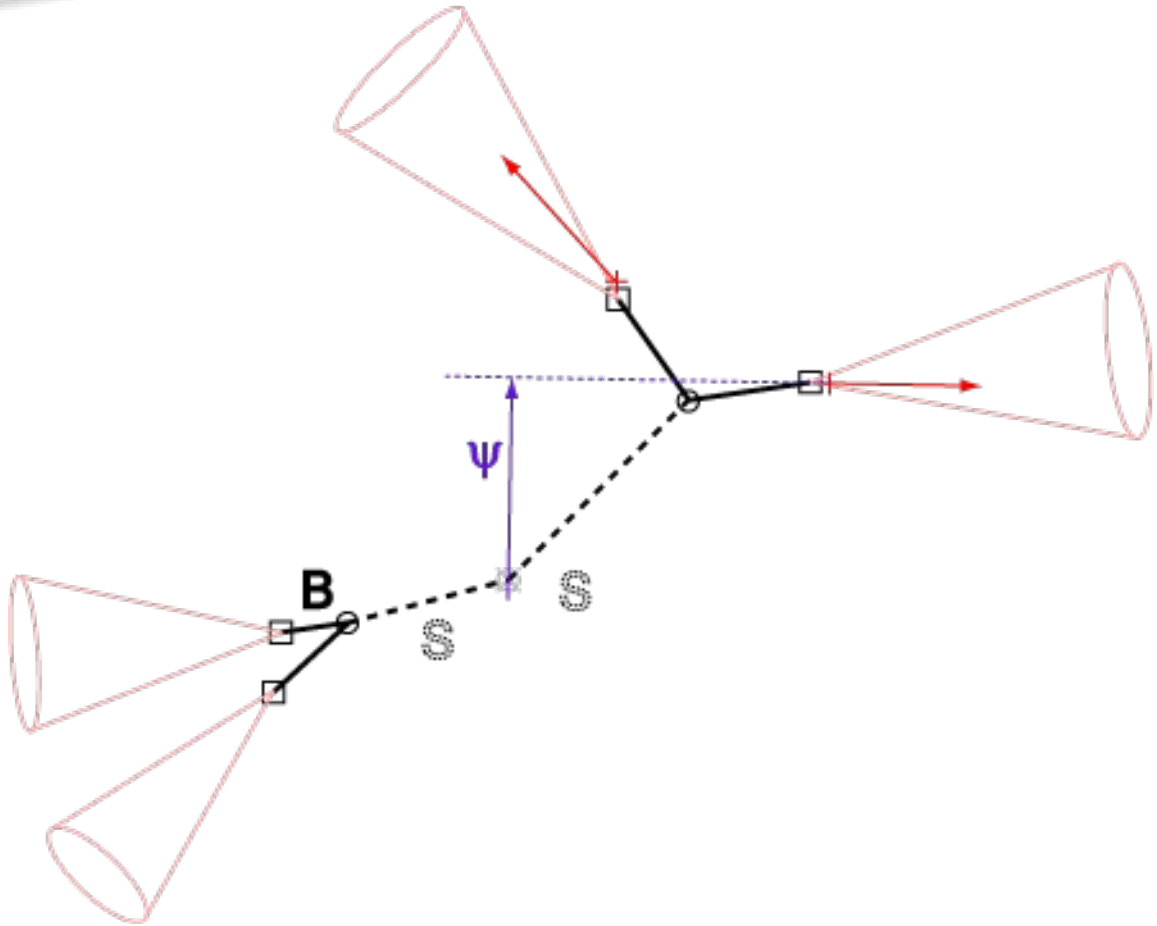
The pink cones represent the hadronization of the B hadrons into jets.

The red represents reconstructed secondary verticies and their corresponding momentum.

MC Studies

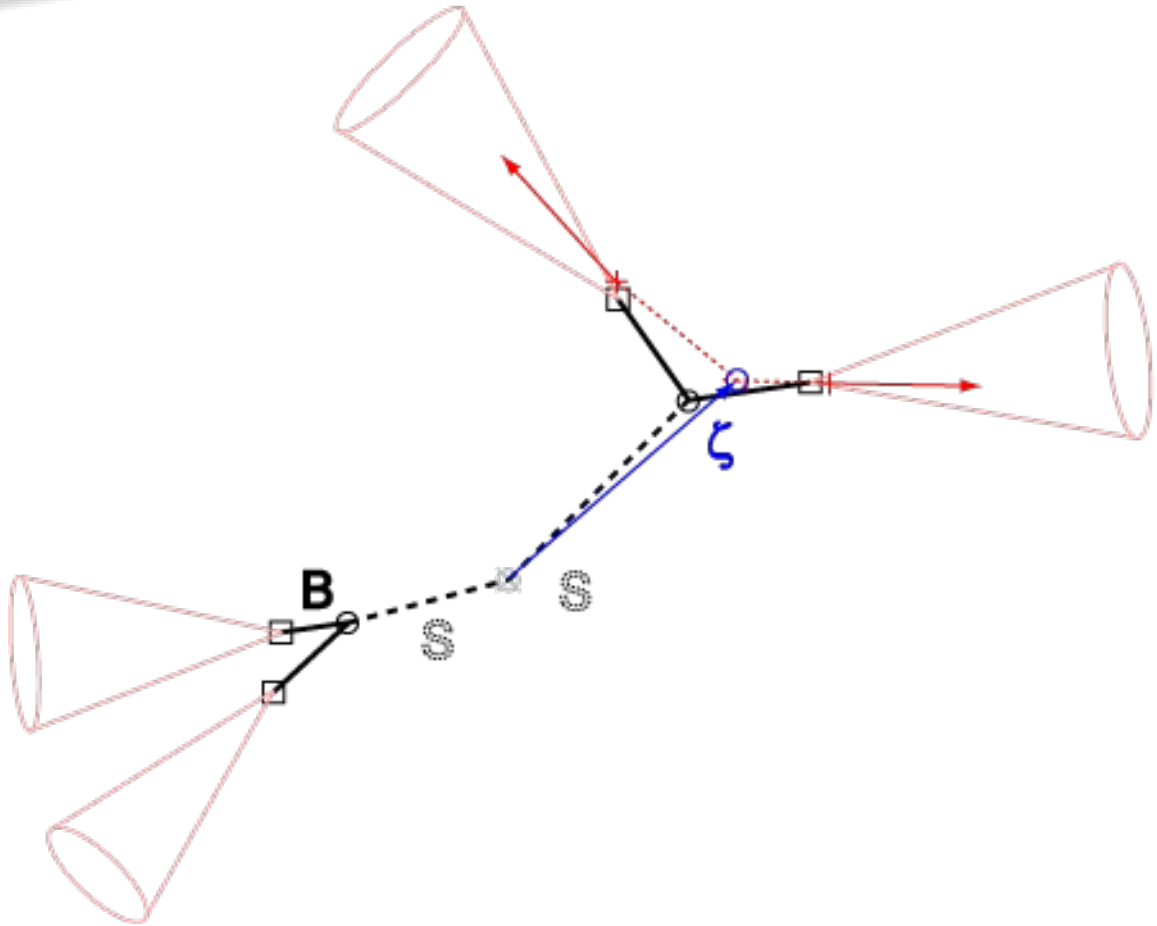
- Compared this signal MC to a background MC, QCD bbbar (also Pythia).
- A tactic of this search is to use SecVtx because it is already used for Top physics.
  - B-tagging is vertexing tracks displaced from the primary vertex to determine if there is a secondary vertex.
  - SecVtx the canonical secondary vertex finder at CDF.
- Unfortunately because SecVtx is designed for Top physics it has certain limitations
  - There is a d_0 cut on tracks considered for vertexing ($d_0 < 0.15$ cm).
    - d_0 is the 2-dimensional distance of closest approach of the track to the primary vertex, i.e. the impact parameter.
  - Our MC study showed that few tracks from a $c\tau = 1$ cm displaced decay vertex will pass this cut.
- As a result we loosened this d_0 cut in the MC for studies.
  - A new b-tagger was written, TStnSVF, which allows me to change this max d_0 cut on tracks easily, without reprocessing all the data.

ψ/ζ Diagrams



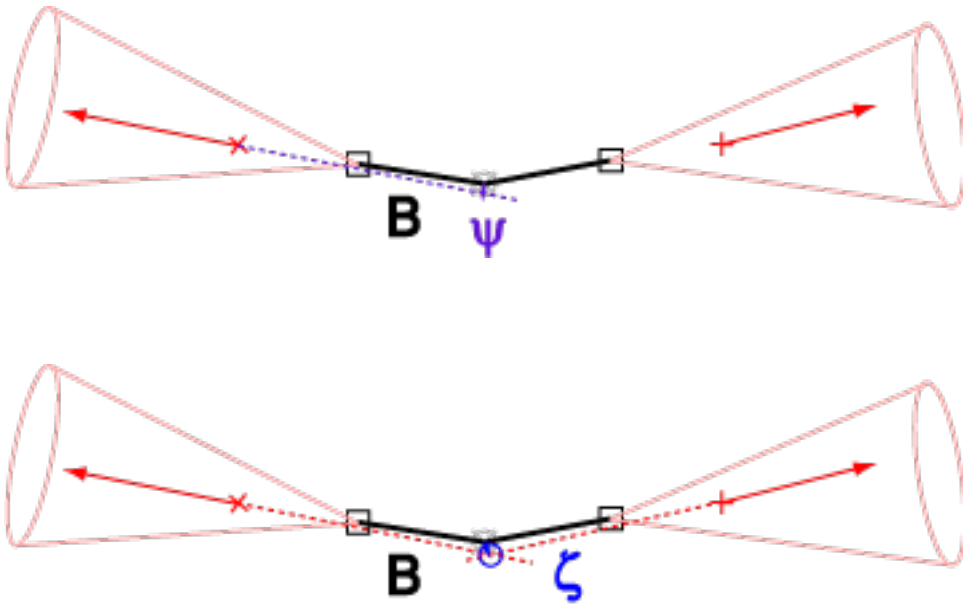
ψ is the impact parameter of a jet with a secondary vertex.

ψ/ζ Diagrams



ζ is the reconstructed decay distance of the heavy pseudoscalar S (A_0). It requires two tagged jets.

Background Diagrams

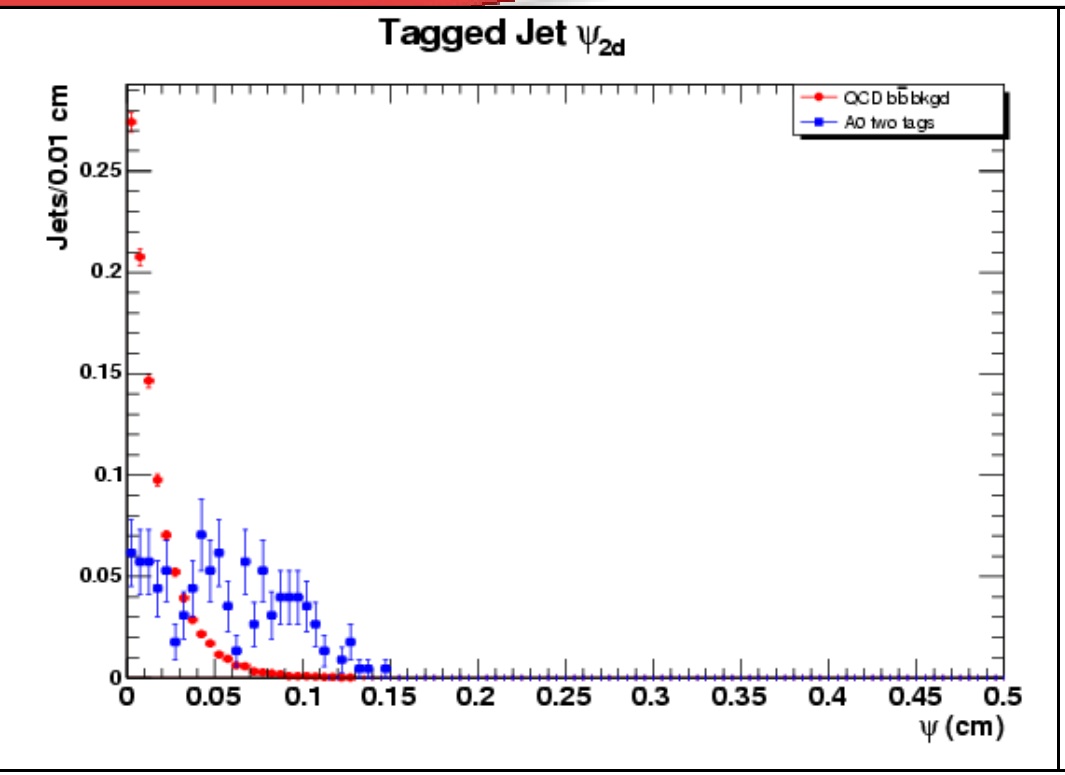


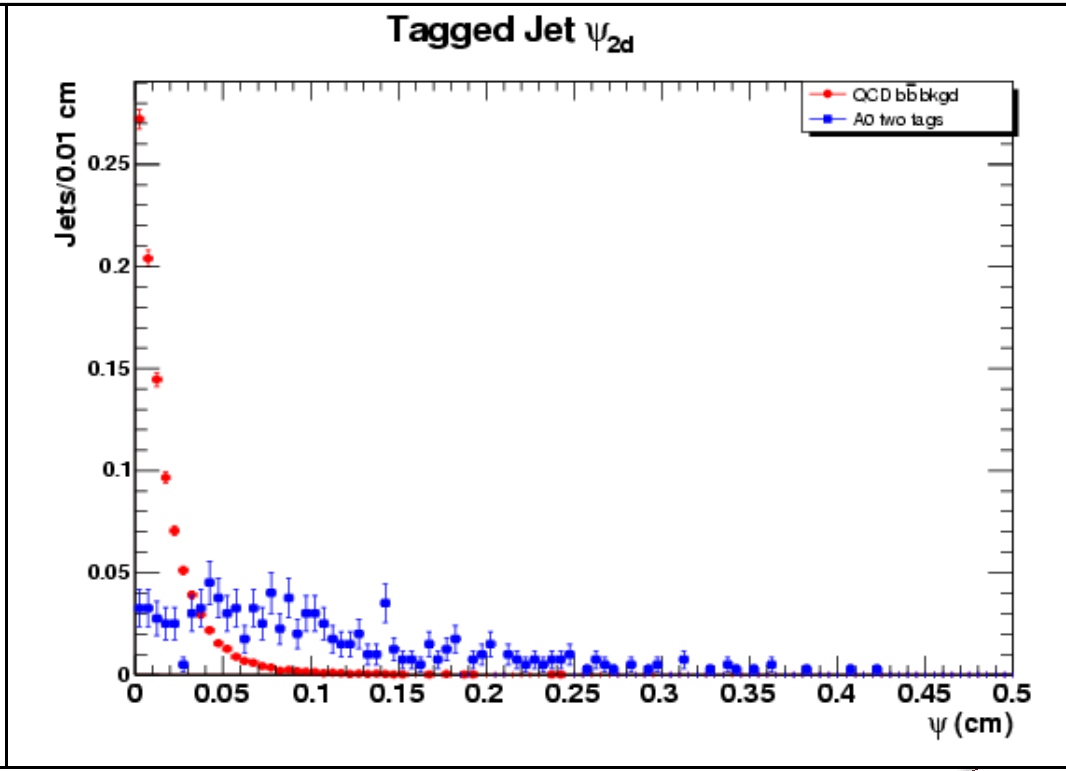
Here is a typical QCD di-jet event with two b quarks (b & bbar) decaying into two B hadrons. Each has a reconstructed secondary vertex represented by a red cross. Both ψ/ζ are very small for these background events.

MC Studies

- New Variables were developed: Psi(ψ) and Zeta(ζ).
- ψ is the impact parameter of the jet.
  - Take the secondary vertex of a jet, it as a position and a direction (momentum), which can be traced back to the primary vertex to give a distance of closest approach (DCA) in 2-dim space.
- ζ is the intersection of multiple jet directions in 2-dim space.
  - This is the reconstructed decay vertex of the A0.
  - It can be positive or negative (like a b-tag).
- There are a few more discriminants of use, but they are not very powerful.
  - Delta R, separation in η-ϕ space, between the jets.
  - Distance between the secondary verticies (ΔS).
  - Average L_{2d} of the secondary verticies.
    - L_{2d} is the two-dimensional distance of the secondary vertex to the primary vertex, projected onto the momentum vector of the jet.
  - ΔS vs. L_{2d}.
- In the histograms on the next slides, I show two different track max d_0 cuts compared to one another.
  - $E_T$min = 10 GeV.
  - $|\eta| < 1.0$, jets must be in the central ($\theta \sim 45^\circ$) of the detector.

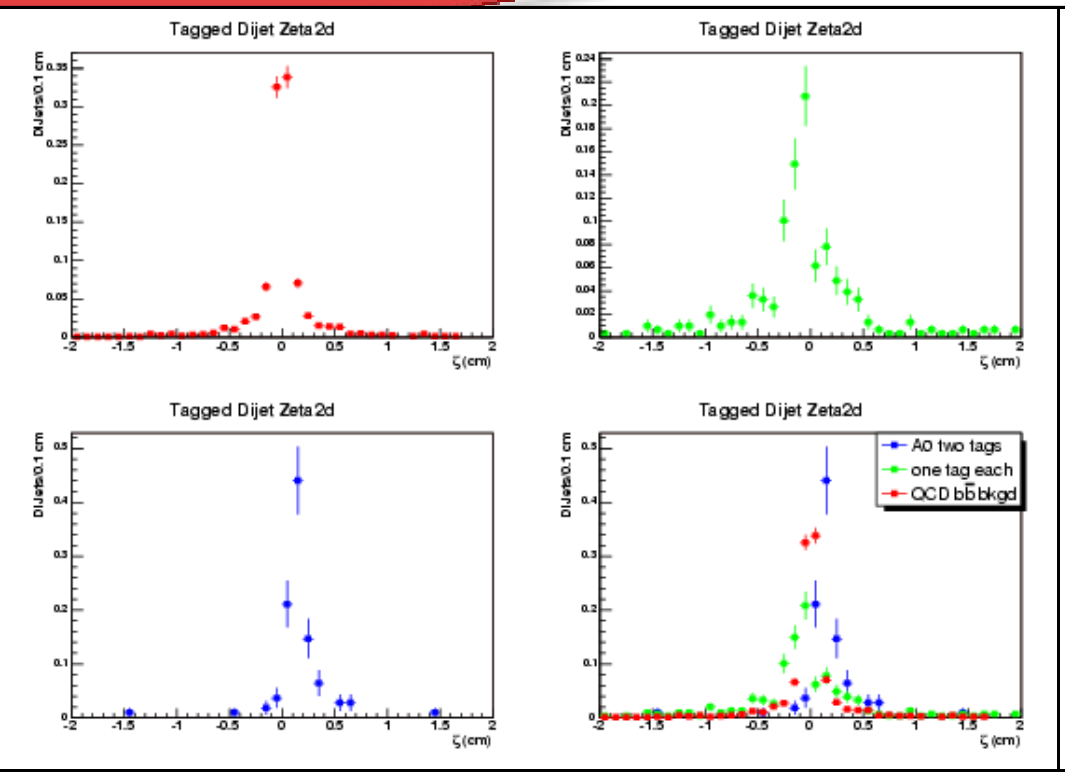
ψ/ζ Histograms

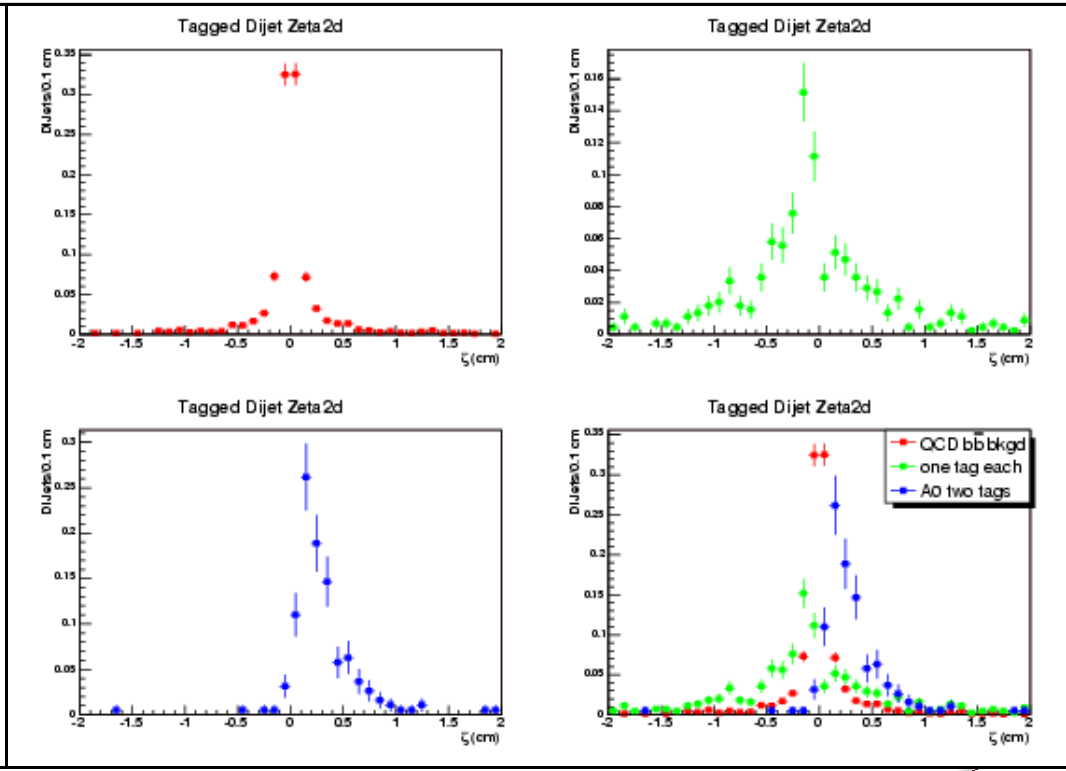




- Left: $d_0 < 0.15$ cm ; Right $d_0 < 0.45$ cm
  - Blue: Signal MC, b-quark jets from A_0s.
  - Red: b, bbar dijet MC for comparison
  - Histograms have been normalized to one.
- This is to give a flavor of what we are looking at, without showing dozens of histograms.
- When the d_0 cut is relaxed, we gain signal events, especially along the tail.

ψ/ζ Histograms





- Left: $d_0 < 0.15$ cm ; Right $d_0 < 0.45$ cm
  - Blue: Signal MC, b-quark jets from A_0s.
  - Green: The case where one tagged b-quark jet is from one A_0 while the other tagged b-quark jet is from the other A_0.
  - Red: b, bbar dijet MC for comparison
- Backgrounds are distributed around zero, while signal is nearly all positive.

Backgrounds

- In the previous histograms I have shown QCD dijet b,bbar MC as background.
  - This was done to provide a visual comparison.
  - The QCD background is much larger than what is shown.
- In addition, Pythia MC is not a very good substitute for the background.
  - Detector effects that create more fake b-tagged jets than MC can model.
- We plan to use data-driven backgrounds for this analysis.

Current Status

- We currently have nearly all the data we need.
  - The data is already processed and at FermiLab.
  - ZBB trigger is our main trigger sample for seaching for signal.
    - Trigger was designed to trigger on quark-jets with displaced tracks within them.
    - However, there is nothing about this trigger that precludes our signal.
    - Two jets (10 GeV) in the central region of the detector ($|\eta|<1.0$), two tracks either $\Delta\phi < 30$ or $\Delta\phi > 150$ in one or both jets.
    - No plug jets greater than 5 GeV. This is to reduce the trigger rate at high luminosities.
  - Large sample of QCD dijets available, with different energy thresholds.
    - 5, 10, 20, 50, 70, 100 GeV
- We have a small sample of signal MC, which you saw here, which we have been using to study the discriminants.
  - But we will need more to be able to set a limit or claim discovery.
  - Need to get the Higgs physics group at CDF to help with this effort.
- We have a b-tagger that can operate on these datasets quickly with very little overhead.
  - Data reprocessing would take too long.

Analysis Strategy

- The analysis strategy is to remove as much of the background as possible. Thus we are searching for any events above zero.
- We need real data based background.
  - MC gets the shapes right, but not the numbers. -Chris Neu
- We will use ψ as our primary variable for background estimation.
  - Build ψ p.d.f.s for “background” jets.
    - Mundane b background: QCD bb, ttbar, ZZ etc.
    - Mundane c background: QCD cc, ZZ
    - Light flavor background: QCD qq/gg
    - (Others such as tau hadronic)
  - Use data triggers when possible to build these p.d.f.s.
    - Muon/Electron calibration data, which is rich is heavy flavor jets
    - Pythia QCD cc MC
    - Single Tower 5, 10 jet data, for light-quark and gluon jets
  - These p.d.f. are per jet (not per event).
  - These per jet p.d.f.s can be applied to multijet QCD production, either data or MC, to estimate the final background and decide on the ψ and ζ cuts.
- Then we use the ZBB trigger data to search for the signal.
  - Make a series of signal region cuts using variables like Delta R, etc.
  - Make the ψ and ζ cuts.
  - Plot the resulting dijet mass distributions.

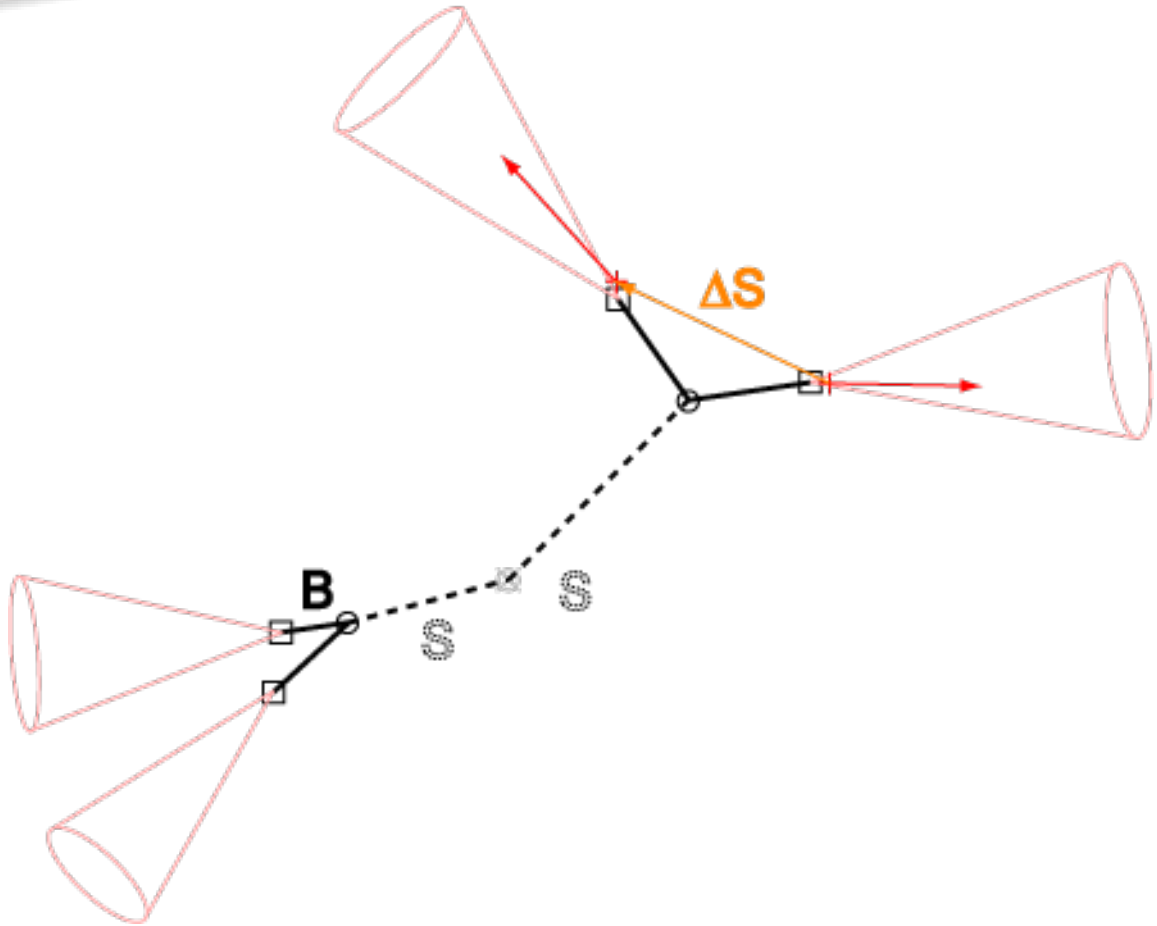
Conclusion

- We are currently working on a displaced vertex search at CDF.
- We have a model, Hidden Valley, which produces the signature which we are looking for.
- Currently we are trying to determine what max-d_0 cut to use for the b-tagger.
  - We are looking at the efficiency in our signal MC as a function of the d_0 cut.
  - We are also looking at the fake tagging rate as a function of this d_0 cut.
  - This is being done with real data from CDF. This will help reduce our backgrounds.
- Goal – finish by the end of the summer.

Backup Slides

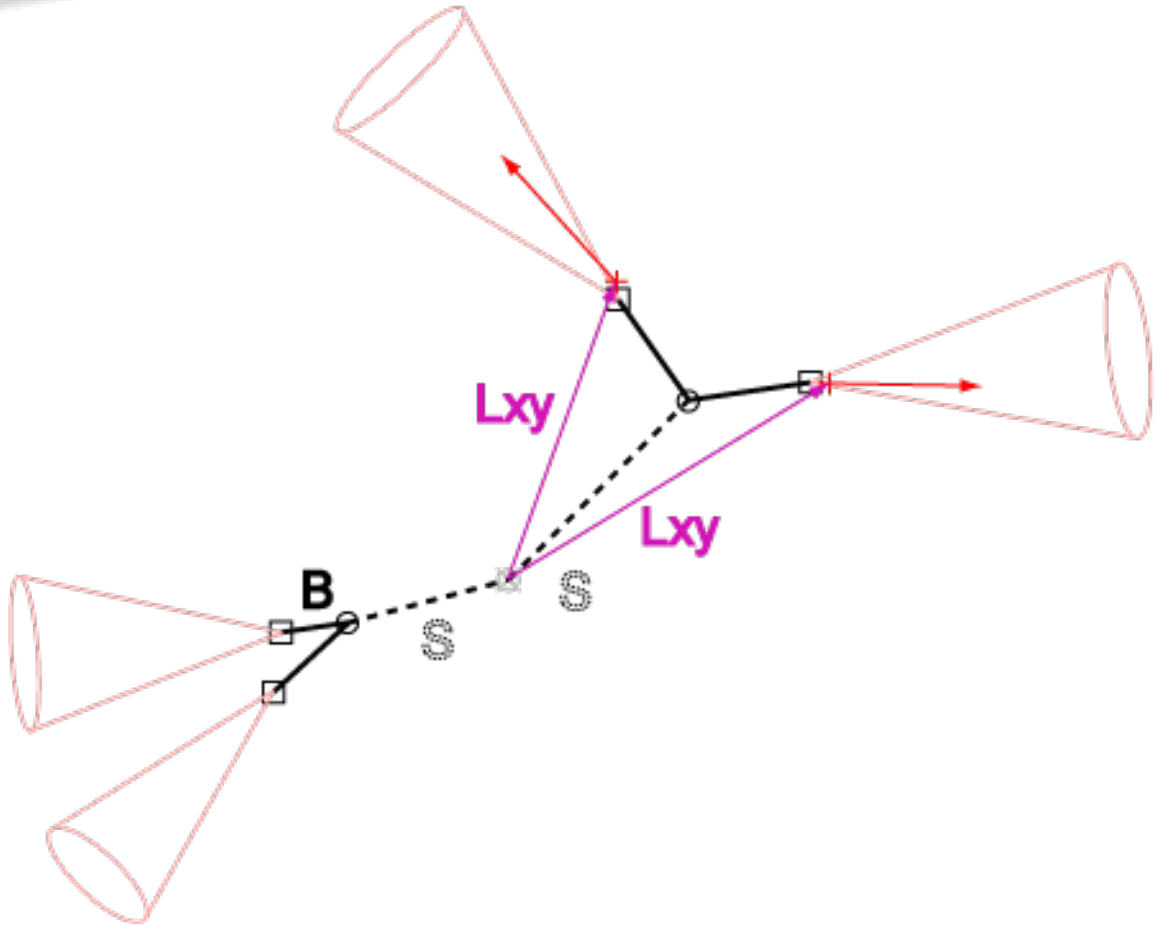
- Additional Diagrams
- Additional Discriminants

Add. Diagrams



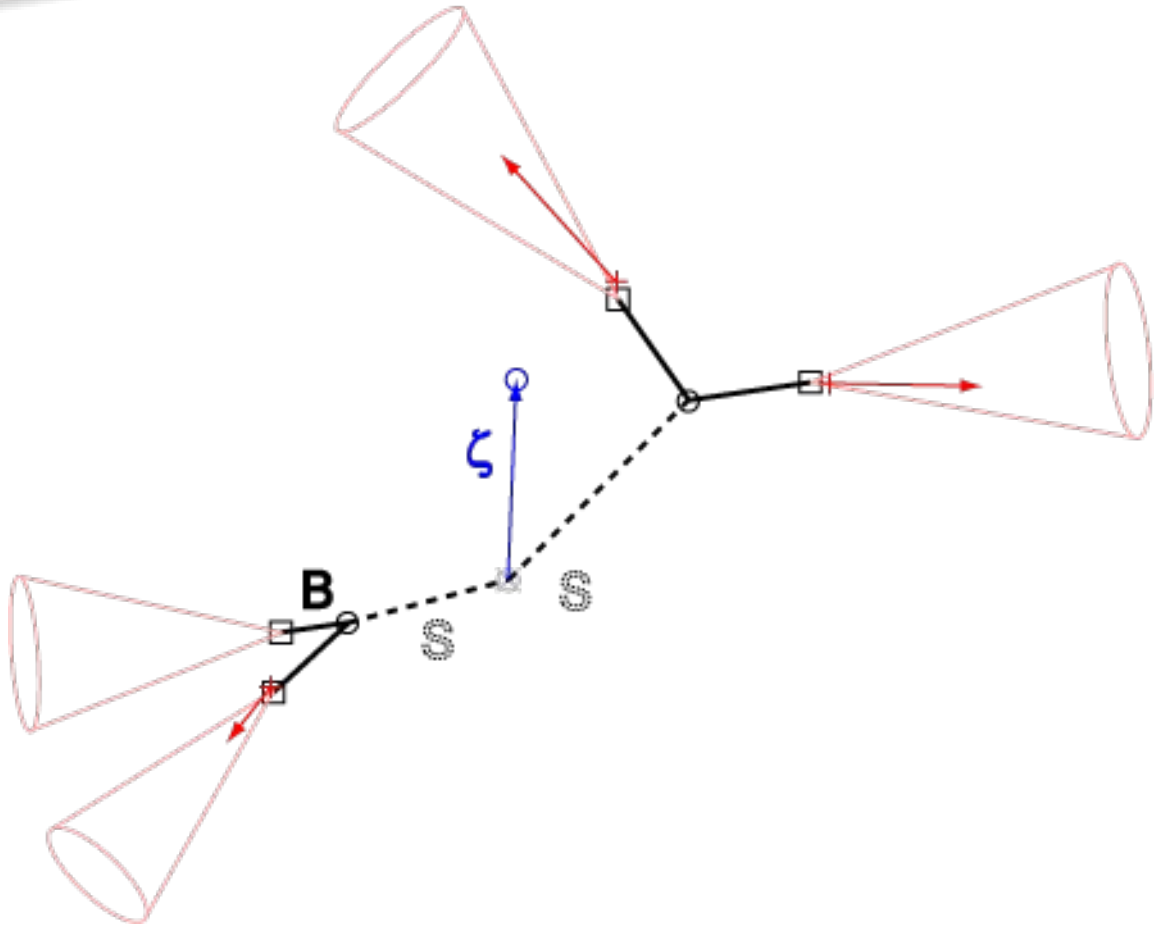
ΔS is the distance between two of the B hadrons decaying from a heavy pseudoscalar S (A_0). It requires two tagged jets.

Add. Diagrams



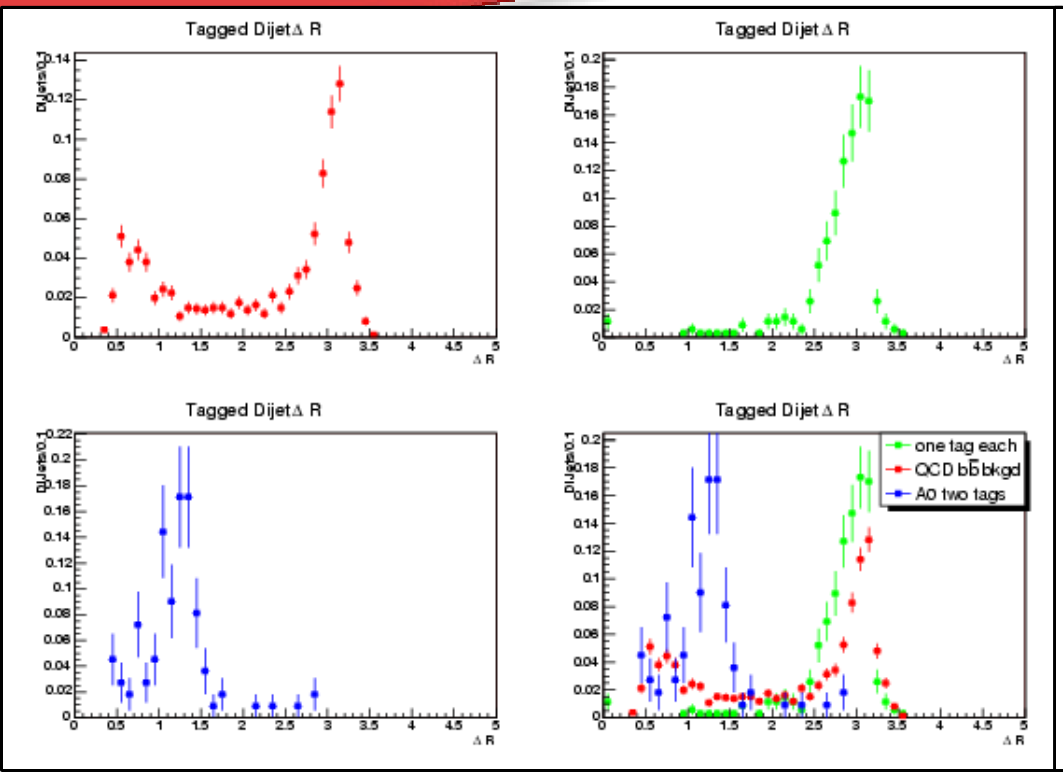
L_{xy} is the two-dimensional distance from the primary vertex to the secondary vertex, shown here for both b-tags. L_{2d} is L_{xy} projected onto the jet momentum vectors (not shown).

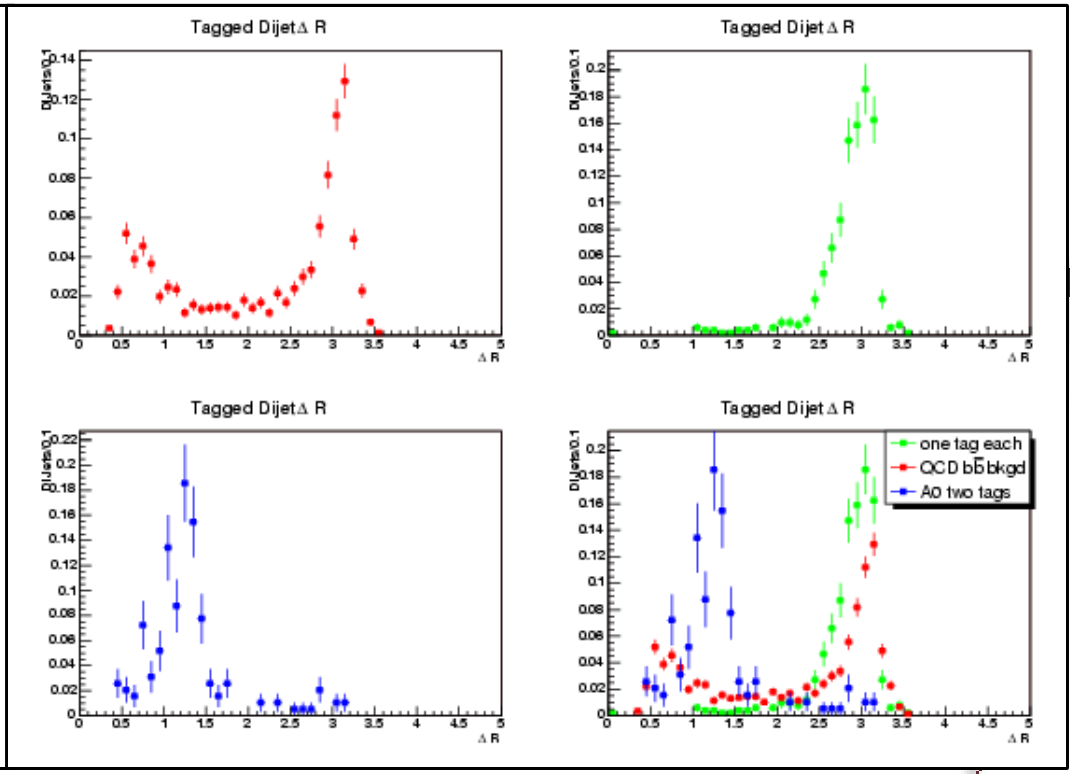
Wrong Combination



If two b quarks, each from a different A_0s, are b-tagged, then the wrong combination may be present. In this case, the B at the lower-left and the B from the upper-right has would have ζ shown above.

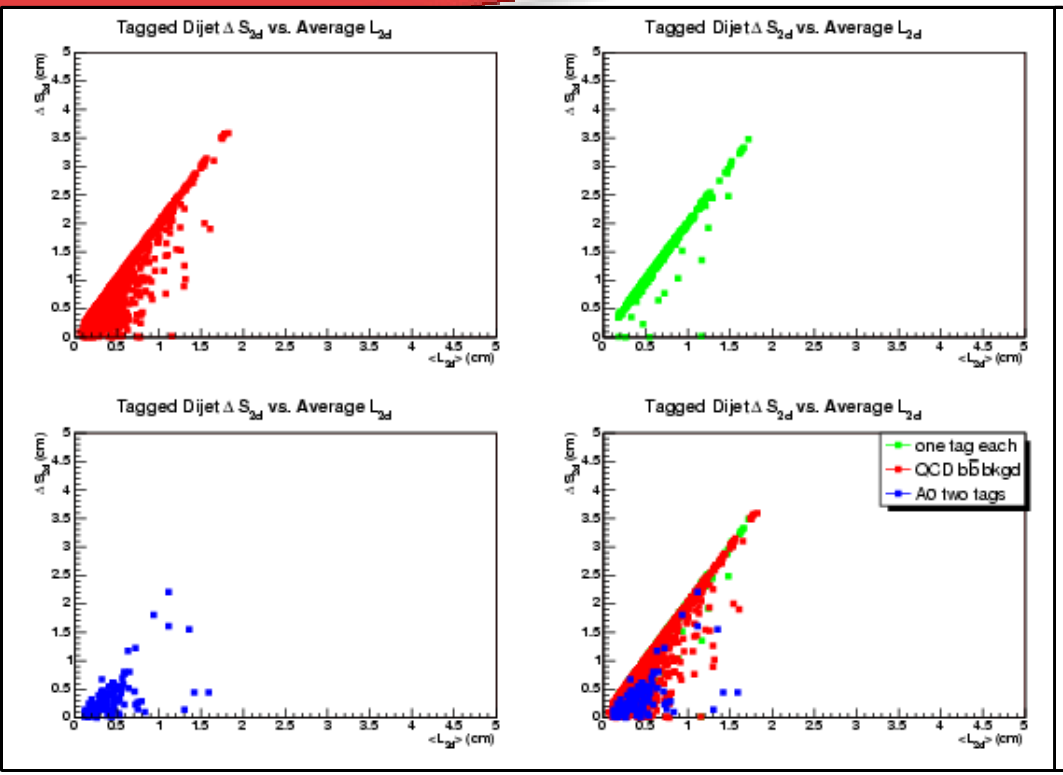
Add. Histograms

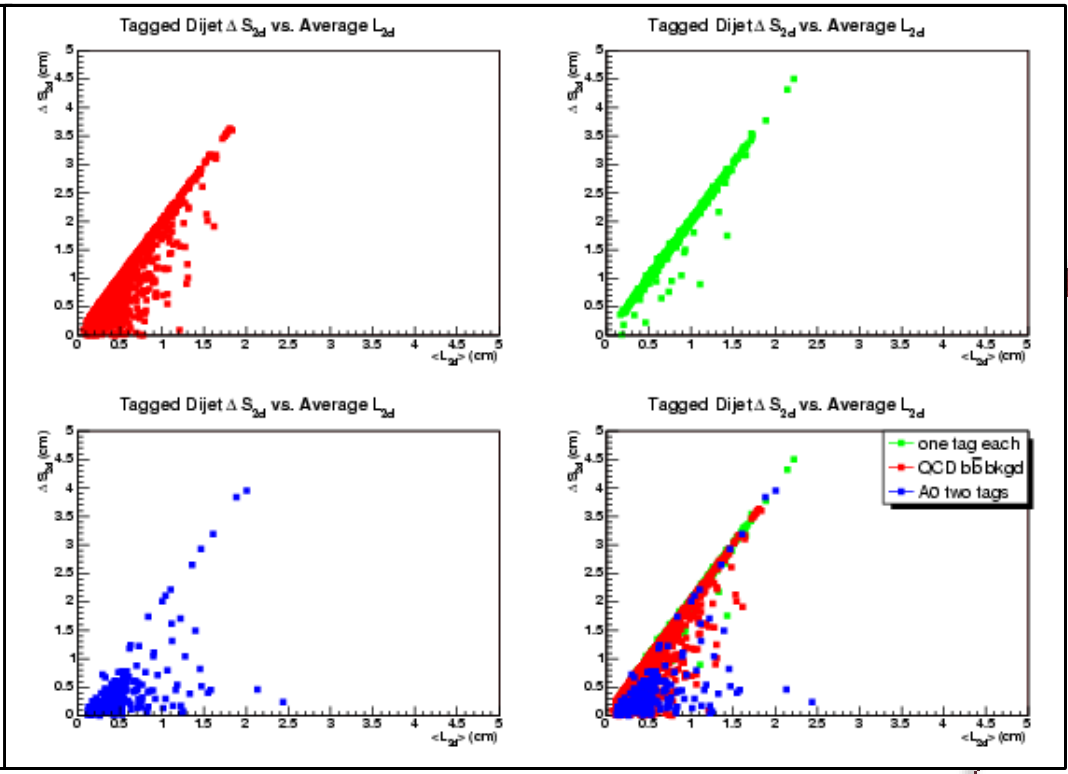




- Left: $d_0 < 0.15$ cm ; Right $d_0 < 0.45$ cm
  - Blue: Signal MC, b-quark jets from A_0s.
  - Green: One tag from each A_0.
  - Red: b, bbar dijet MC for comparison
  - Histograms have be normalized to one.
  - ΔR for signal is much smaller than for background.

Add. Histograms





- Left: $d_0 < 0.15$ cm ; Right $d_0 < 0.45$ cm
  - Blue: Signal MC, b-quark jets from A_0s.
  - Green: One tag from each A_0.
  - Red: b, bbar dijet MC for comparison
- The x-axis the $<L_{2d}>$ of the two tagged b-jets, the y-axis is the distance between the two secondary veritices.
  - QCD and wrong combo. backgrounds follows a diagonal line.
  - Signal has large $<L_{2d}>$ but small ΔS.